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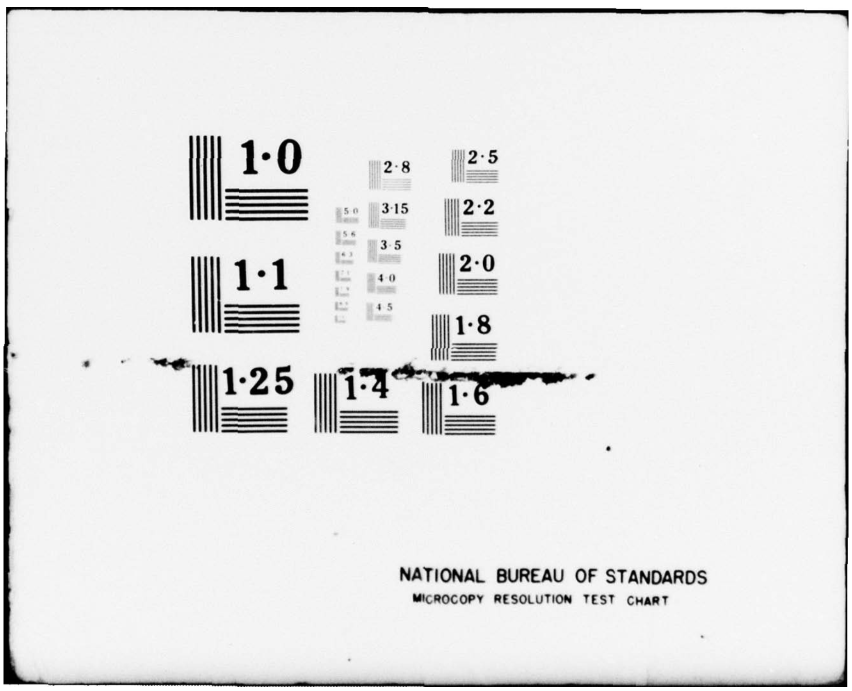
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THE REGENERATION OF SOUTH CHINA SEA TROPICAL CYCLONES IN THE BAY OF BENGAL

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MAY 1977

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Rarely does a tropical cyclone cross from the South China Sea, weaken over Southeast Asia, and regenerate into a tropical cyclonic storm in the Bay of Bengal. During the 7-year period 1967-73, there were only three occurrences of this phenomenon -- and two of these occurred in September 1972. Analyses of the atmospheric circulations during

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20. Abstract (continued)

September 1972 lead to a tentative hypothesis of the combination of factors required for this rare event.

CONTENTS

1. INTRODUCTION

A very small percentage of cyclonic storms* in the Bay of Bengal are formed by the regeneration of systems which were previously tropical storms or typhoons in the South China Sea and thereafter weakened in crossing Southeast Asia or Malaya.

However, the probability of such an occurrence is of concern to naval units operating in the area and especially to the Joint Typhoon Warning Center (JTWC), Guam which provides tropical cyclone forecasts for the Bay of Bengal. Such an occurrence is very unlikely in the spring when the atmospheric circulation is more favorable for storm development in the Bay of Bengal than in the western North Pacific Ocean or South China Sea. However, in the fall, conditions favor storm development in all three areas (see mean circulations for May and October in Sadler and Gidley, 1973) and there are, on the average, as many or more tropical storms and typhoons in the South China Sea to the west of 110E as there are storms in the Bay of Bengal. This paper examines the tropical cyclone characteristics in the two areas during a recent period (1967-1973) of good satellite and synoptic data to determine if tropical cyclones in the South China Sea can maintain a circulation after crossing Southeast Asia or Malaya and then reintensify in the Bay of Bengal.

2. DATA SOURCES

a. Satellite. The principal satellite data source was the daily tropical mercator-projection mosaic produced by the National Environmental Satellite Service (NESS). This was

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*The India Meteorological Department classifies tropical cyclones as: tropical depression -- winds less than 34 kt; cyclonic storm -- winds 34 to 47 kt; severe cyclonic storm -- winds greater than 47 kt.

supplemented for selected periods during 1972 and 1973 by Defense Meteorological Satellite Program (DMSP) photographs from the U.S. Air Force station in Thailand.

b. Synoptic Data. The principal synoptic data sources were the operational analyses (on microfilm) from the Royal Observatory, Hong Kong. The surface and 850-mb analyses were available four times daily and the higher levels (through 200 mb) twice daily.

c. Tropical Cyclone Histories

(1) South China Sea: Annual Typhoon Reports of JTWC, Guam.

(2) Bay of Bengal: Tropical Cyclones of the North Indian Ocean (Sadler and Gidley, 1973); the Weather Section of the appropriate issues of the Indian Journal of Meteorology and Geophysics; Annual Typhoon Reports of JTWC (beginning in 1971) for cyclones forming or passing through the area east of 90E.

3. PROCEDURE

All South China Sea tropical storms and typhoons which crossed 110E were stratified by month and their tracks were plotted (Figures 1-4). Dates of landfall, or over-ocean dissipation, were entered. Tracks were also plotted of all tropical cyclones which attained cyclonic storm intensity or greater in the Bay of Bengal and the dates were noted of the early depression stage. The dates of the two sets of tracks were then compared. From a consideration of timing, those Bay of Bengal cyclones which could have originated from the South China Sea were identified. These were then studied in detail by using satellite and synoptic data to determine which South China Sea cyclones crossed Southeast Asia or the Isthmus of Kra, weakened, and then regenerated into cyclonic storms in the Bay of Bengal.

4. DISCUSSION

In June, July and August there were only monsoon depressions in the Bay of Bengal. The majority formed north of 18N and none were associated with previous storms in the South China Sea. One storm formed in the Bay of Bengal in April 1972 and one each in December 1968 and 1969, but none could be associated with a previous storm in the South China Sea.

a. May (Figure 1). As mentioned earlier, the spring storm season in the Bay of Bengal has no counterpart in the South China Sea, so obviously there is no storm link between the two areas.

b. September (Figure 2). In September the Bay of Bengal experiences a mixture of monsoon depressions (not shown) and a few cyclonic storms, mostly north of 15N.

In the South China Sea the storm tracks are concentrated between 15N and 20N. In 1972, Typhoons Elsie and Flossie maintained well developed circulations while crossing 1200 km of rugged terrain including two coastal mountain ranges. They then regenerated into cyclonic storms in the Bay of Bengal. These will be discussed later. In 1969 the remnants of Doris also crossed, but failed to regenerate into a cyclonic storm.

c. October (Figure 3). From September to October the storm generating area in the Bay of Bengal and the storm tracks in the South China Sea shift southward to between 10N and 18N. In 1970 the remnants of Typhoon Kate crossed Southeast Asia but failed to reintensify. None of the eight storms in the Bay of Bengal was associated with any of the nine storms in the South China Sea.

d. November (Figure 4). The development area in the Bay of Bengal and the storm tracks in the South China Sea continue their southward shift from October to the latitudes

of 7N to 13N in November. The frequent interaction of fall typhoons with cold northeast surges in the South China Sea is reflected in tropical cyclone weakening and a path change from WNW near 115E to WSW at 110E. Many of these weakened systems traverse the Gulf of Thailand and some cross the Isthmus of Kra, but regeneration is rare. The only exception was Tropical Storm Sarah in 1973. In the seven years, Typhoon Sally (1972) was the most intense system in the Gulf of Thailand and still a tropical storm at landfall on the Kra Isthmus, yet it failed to regenerate in the Bay of Bengal.

e. May-November Summary (1967-1973). Three of the 26 tropical cyclones which eventually reached tropical storm intensity or greater in the Bay of Bengal were regenerated South China Sea tropical storms or typhoons. Conversely, three of the 28 tropical cyclones in the South China Sea which passed west of 110E as tropical storms or typhoons subsequently reintensified into cyclonic storms in the Bay of Bengal. Two of the three were Typhoons Elsie and Flossie in September 1972.

For such a rare event to occur twice in the same month suggests a circulation anomaly favorable for maintaining a tropical cyclone for three to four days over rugged terrain. The September storm tracks (Figure 2) show that Elsie and Flossie were south of normal when they entered the South China Sea south of 15N. Typhoon Doris, with a similar track, also crossed Southeast Asia, but failed to reintensify. The monsoon trough was apparently south of normal during these periods and was oriented east-west from the western Pacific across Southeast Asia.

5. MEAN CIRCULATION DURING SEPTEMBER 1972

In 1972 the monsoon trough at 850 mb and 700 mb (Figures 5 and 6) was more intense in the western Pacific and further south than normal across the Philippines, the South China Sea,

and Southeast Asia (Sadler and Harris, 1970; or Ramage and Raman, 1972). During September 1972, persistent lower tropospheric westerlies extended as far east as 180 degrees longitude. The subtropical ridge in the western Pacific and East China Sea was also south of its normal position. Instead of winds with a normal southerly component, zonal easterlies covered the South China Sea and western Pacific north of 15N. For example, the slightly north-of-east winds in 1972 at Clark AFB and Guam contrast to normal SSW at Clark and SE at Guam. These anomalies reflected a very sharp east-west trough from the Bay of Bengal to the dateline.

Four typhoons and a tropical storm formed in the trough during September. Helen and Ida became typhoons east of 130E and moved northward. Tropical Storm Grace dissipated before reaching the Philippines. The depression stages of Elsie and Flossie formed in the trough and drifted westward across the Philippines before intensifying in the South China Sea. Each attained maximum winds of 75 kt just prior to landfall in Vietnam. Both of these storms eventually regenerated in the Bay of Bengal.

The south-of-normal tracks contributed to the abnormal histories of Elsie and Flossie, but were not the controlling factor since the storm paths in October and November are even farther south than in September. The fact that September storms in the South China Sea are not subject to the decaying influence of cold northeast surges (as are some in October and most in November) cannot be a controlling factor because, from Figure 3, it is obvious that the majority of October storms enter Vietnam without encountering northeast surges, yet most then decay rapidly. The most important factor appears to be the role of the anomalous circulation within which the storm is embedded (see following section).

6. HYBRID SYSTEMS IN THE SOUTH CHINA SEA

It has been noted (Sadler _et al_., 1968) that typhoons and tropical storms which develop in the South China Sea in summer sometimes organize the already existing, very large, synoptic-scale cyclonic trough into a huge, deep, cyclonic vortex whose peripheral speeds at a radius of > 500 km may reach 40 kt or greater. During the decay phase over land, these hybrid systems, in which the typhoon is only a small embedded part of the total vortex, behave differently from a normal typhoon whose circulation usually shrinks rapidly and weakens after passing inland, particularly over rugged terrain. The hybrid cyclone, however, maintains a large, well developed circulation for two to three days after crossing the coast even though the storm core may decay in the normal manner. Typhoon Ora in July 1966 (Sadler _et al_., 1968) is an example. Ora developed slowly within a deep, 2000-km diameter cyclonic vortex covering the entire South China Sea and reached maximum winds of 85 kt just before crossing the South China coast on a northwest path. On 25 July at 0000 GMT when Ora was southeast of Hainan Island at 18.4N, 112E with winds of 70 kt, winds on the periphery were reported as follows:

	850 mb	700 mb	500 mb	
Saigon	26035	24038	25027	900 km SW of center
Clark	18035	18022	21020	900 km SE of center
Hong Kong	11037	11032	09029	500 km ENE of center

The vortex surrounding Ora finally broke up over the mountains of south central China two days after crossing the coast.

Typhoons Elsie and Flossie were embedded in similar circulations. Figures 7-11 show the circulations at 850, 700, 500, 300, and 200 mb after Elsie had crossed the Annam

Mountains of Vietnam and Laos and was located just southwest of Ubon, Thailand. The surrounding vortex covers most of Southeast Asia and extends through 300 mb. Even at 200 mb it is within the tropical upper tropospheric trough which extends westward from the Pacific into Southeast Asia. The surface low (not shown) had filled to about 998 mb and there were no strong surface winds reported. However, the observed 850- and 700-mb winds at Ubon were 45 and 40 kt, respectively. The satellite observation near 0700 GMT on 5 September 1972 (Figure 12a) shows a well organized cloud system associated with Elsie. Elsie remained within the very deep, large scale vortex and maintained winds of 40 to 45 kt across Southeast Asia. As she passed to the north near 1200 GMT on 6 September, the strongest observed wind at Bangkok was 45 kt from 170° at 700 mb. The rugged mountains on the border between Thailand and Burma had little effect on the very large scale vortex, but there were no nearby data to determine if the winds of Elsie decreased to less than tropical storm intensity. In any event, she was of storm intensity shortly after leaving the Burma coast and attained maximum winds of 80 kt in the Bay of Bengal prior to entering India on a northwest path on 10 September at 19N. The organized vortex containing the embedded Elsie continued to be very large and deep. It covered most of the Bay of Bengal on the 8th and 9th and moved into India with the storm. Figure 13 shows the large scale wind field at 500 mb on 11 September after Elsie had moved some 500 km inland over the Eastern Ghats. The satellite photographs near 0845 GMT on 12 September (Figure 12b) and 13 September (not shown) confirm that the storm system remained well organized for at least three days and 1200 km inland over the rugged hills of North Central India.

Flossie followed Elsie in 12 days and had a similar history. She was embedded in a large cyclonic circulation which also extended to 200 mb. However, the maximum winds measured by the Thailand rawin network during the passage of

Flossie were about 10 kt less. The strongest winds at Ubon were 30, 40, and 35 kt at 850, 700, and 500 mb respectively. In the satellite picture of 16 September (Figure 12c) Flossie has just passed over the Annam Mountains. No digital pictures were available for 17-20 September. Flossie traversed a more extensive mountain mass than did Elsie, farther to the south.

Flossie reintensified to 70 kt in the Bay of Bengal and entered India at about the same point as Elsie. The satellite view on 25 September (Figure 12d), three days after crossing the coast, shows Flossie less well organized and weaker than Elsie at the same stage.

7. SUMMARY

A tropical cyclone of tropical storm or typhoon intensity in the South China Sea rarely maintains a circulation while crossing Southeast Asia or the Malay Peninsula or reintensifies in the Bay of Bengal. If the seven-year period of the study is typical, the event is most probable during the late summer month of September.

This study indicates that the following combination of factors probably contributes to the event: (1) the low level trough and subtropical ridge are south of normal in the western Pacific-South China Sea so that a disturbance enters the South China Sea south of 15N; (2) the disturbance first intensifies in the South China Sea, which it is felt, leads to development of the third and most important factor; (3) a very large, deep, synoptic-scale cyclone surrounding the storm. Systems which have been typhoons prior to entering the South China Sea are likely to have a typical typhoon structure and environments not favoring development of a hybrid type cyclone.

Many October storms satisfy factors (1) and (2). Case studies of these to determine if any satisfy factor (3) would provide a test of this tentative hypothesis.

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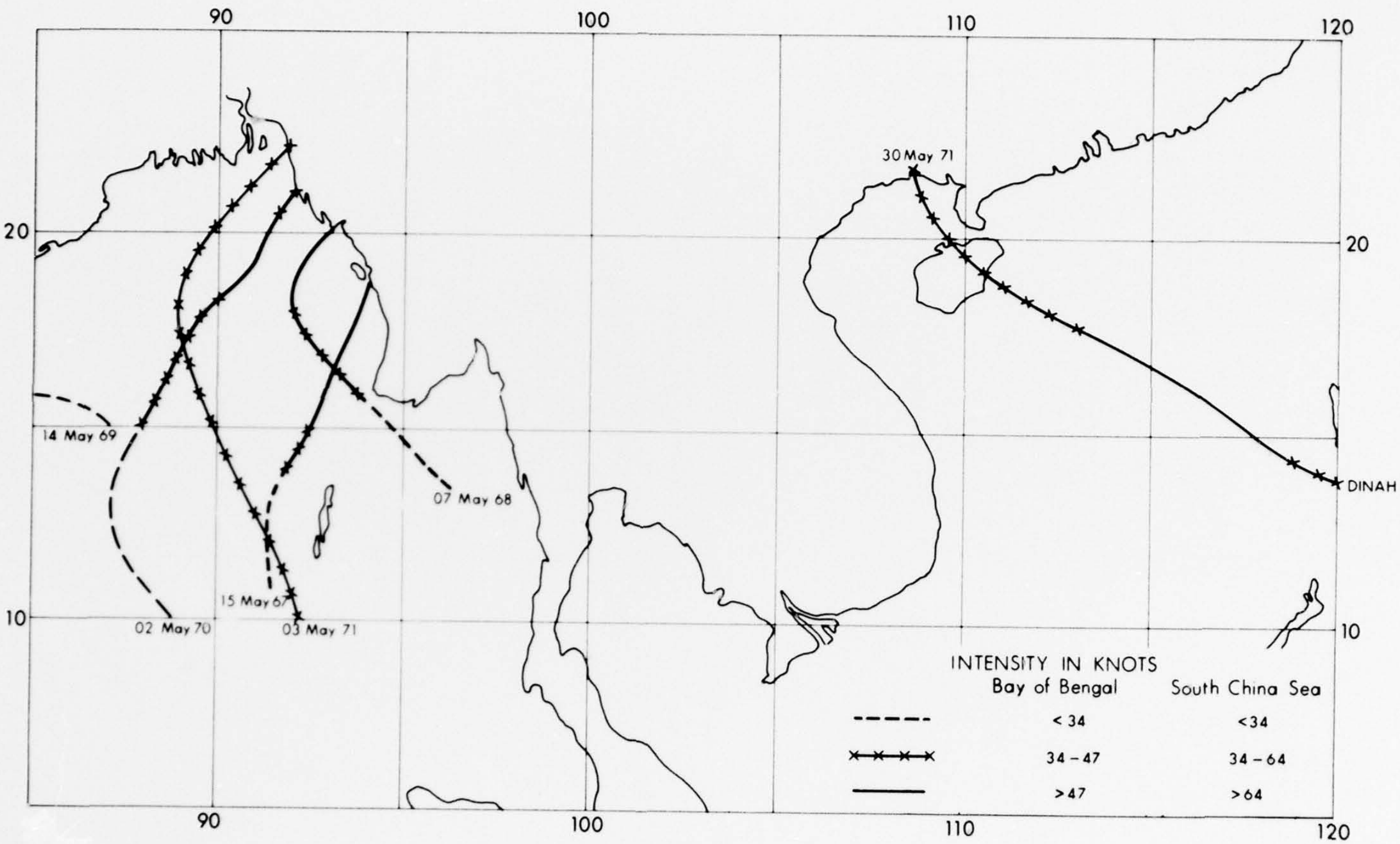

Figure 1. May storm tracks in the Bay of Bengal and the South China Sea for 1967-1973.

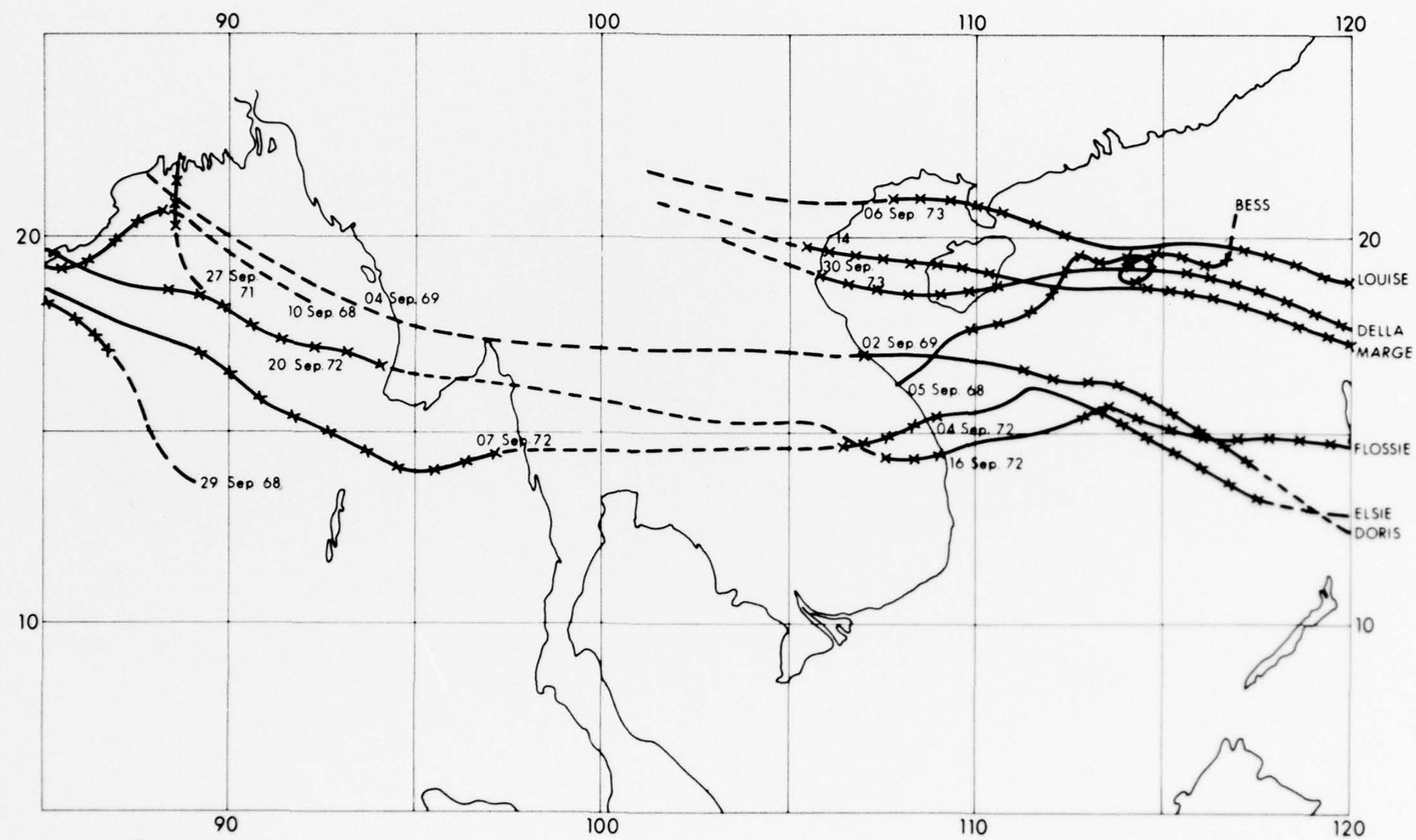

Figure 2. September storm tracks in the Bay of Bengal and the South China Sea for 1967-1973.

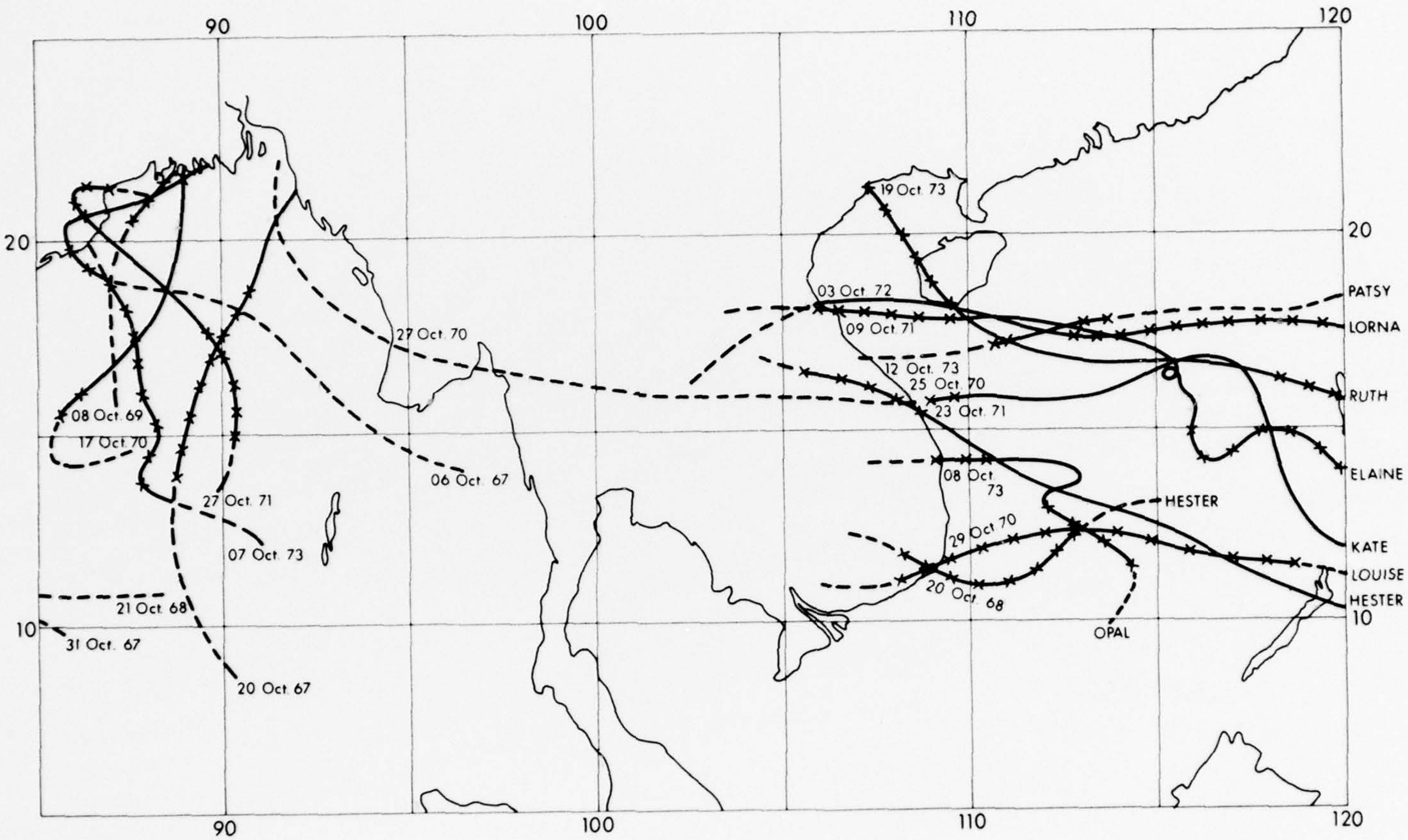

Figure 3. October storm tracks in the Bay of Bengal and the South China Sea for 1967-1973.

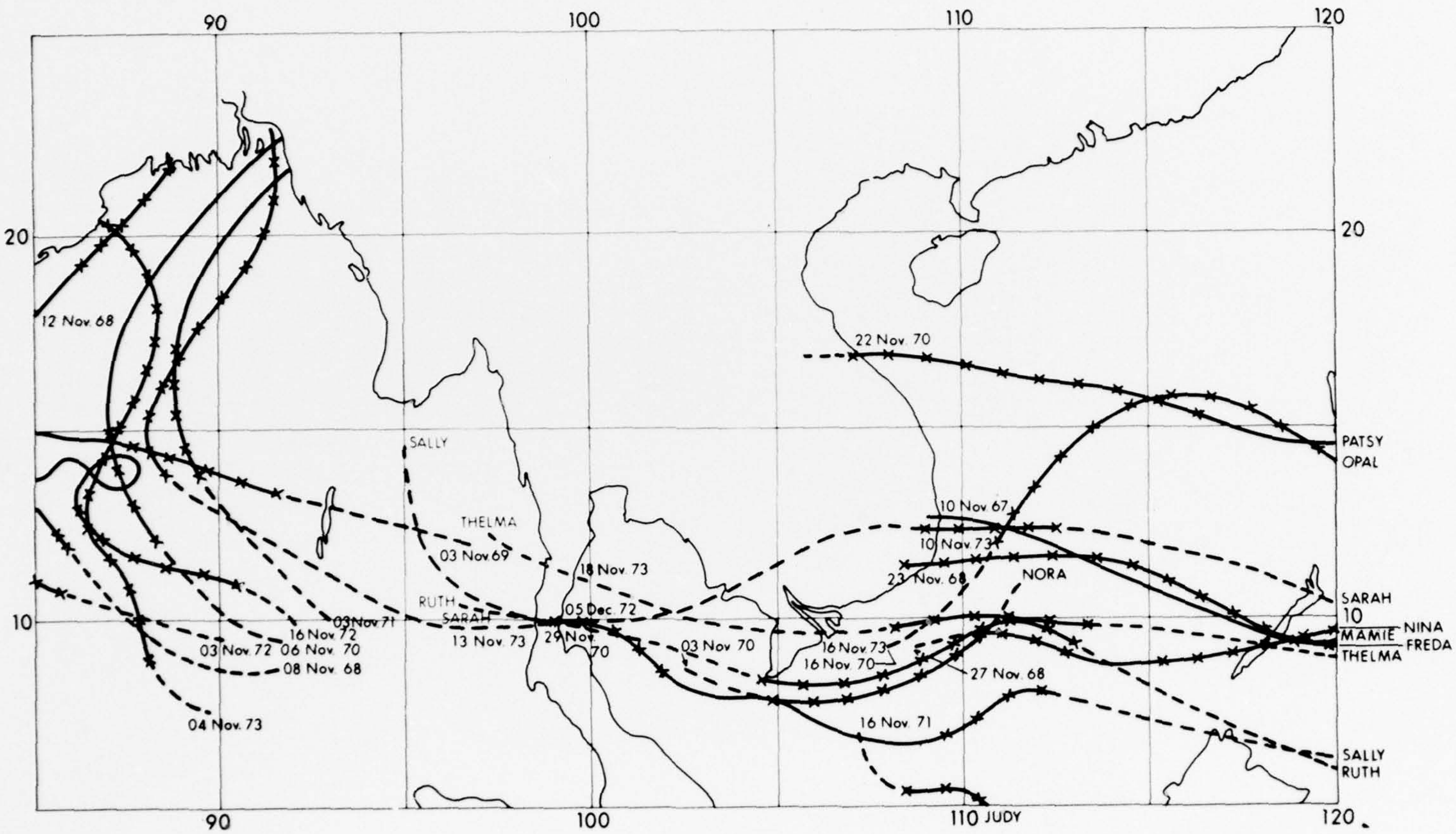

Figure 4. November storm tracks in the Bay of Bengal and the South China Sea for 1967-1973.

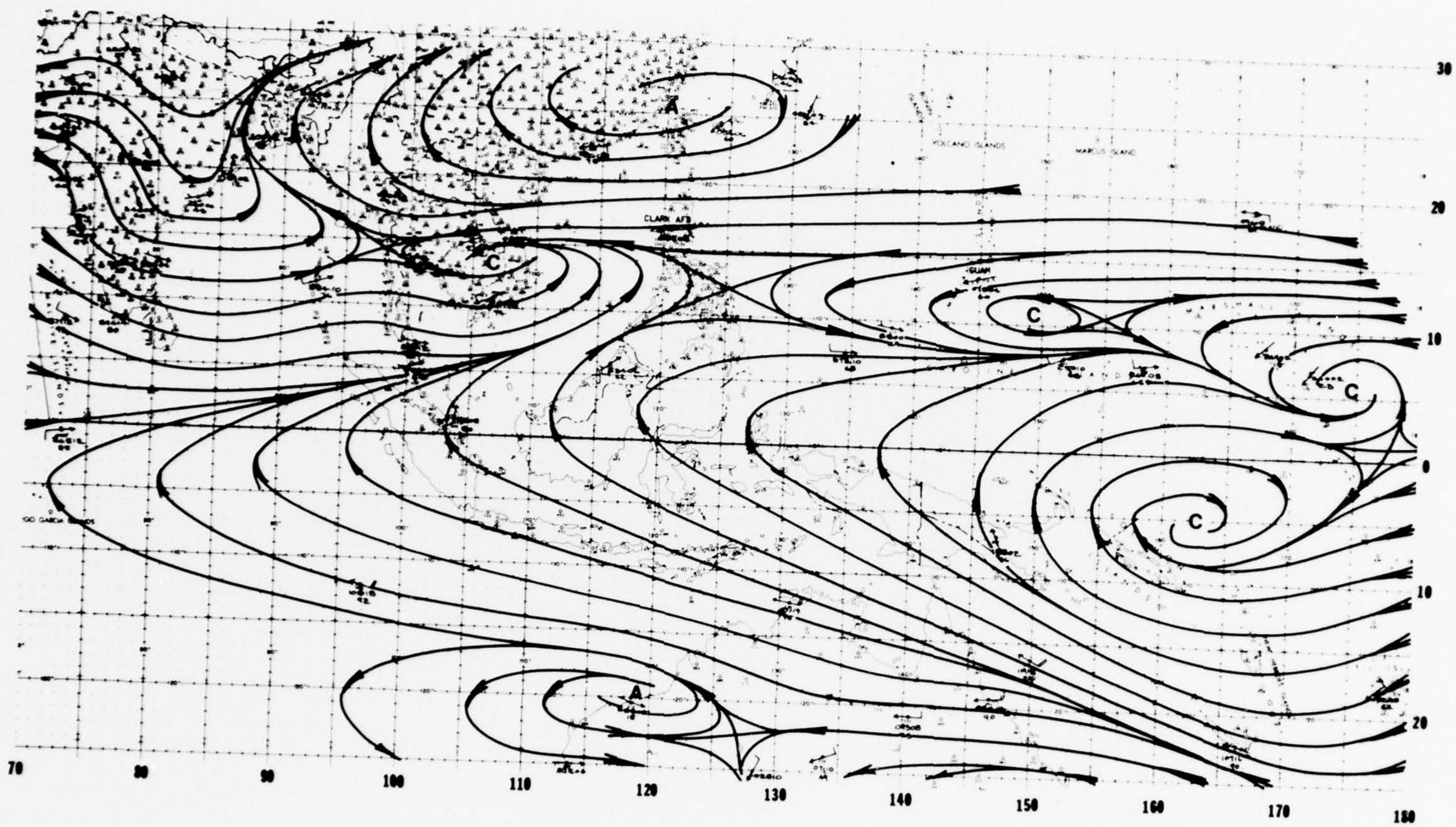

Figure 5. Mean 850 mb circulation for September 1972.

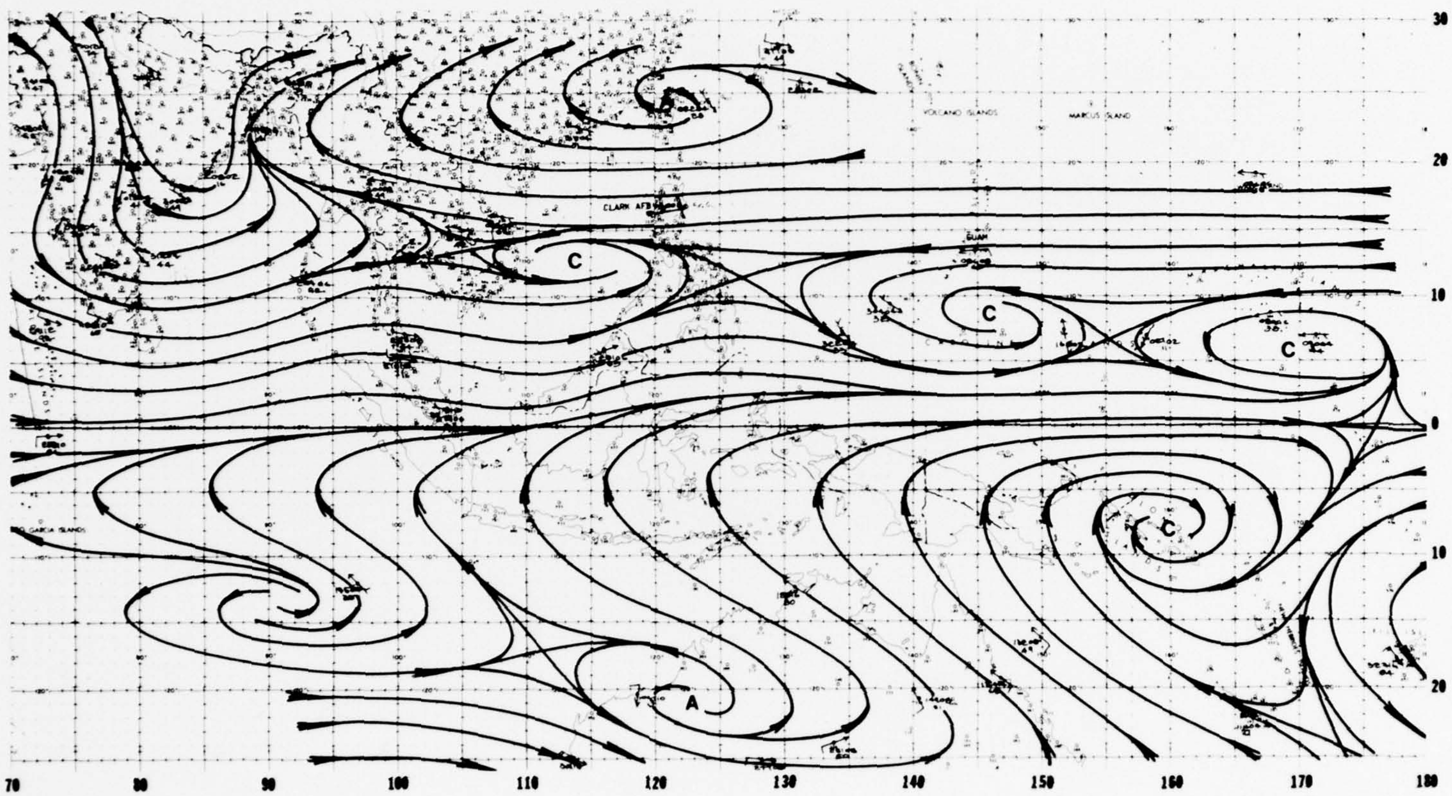

Figure 6. Mean 700 mb circulation for September 1972.

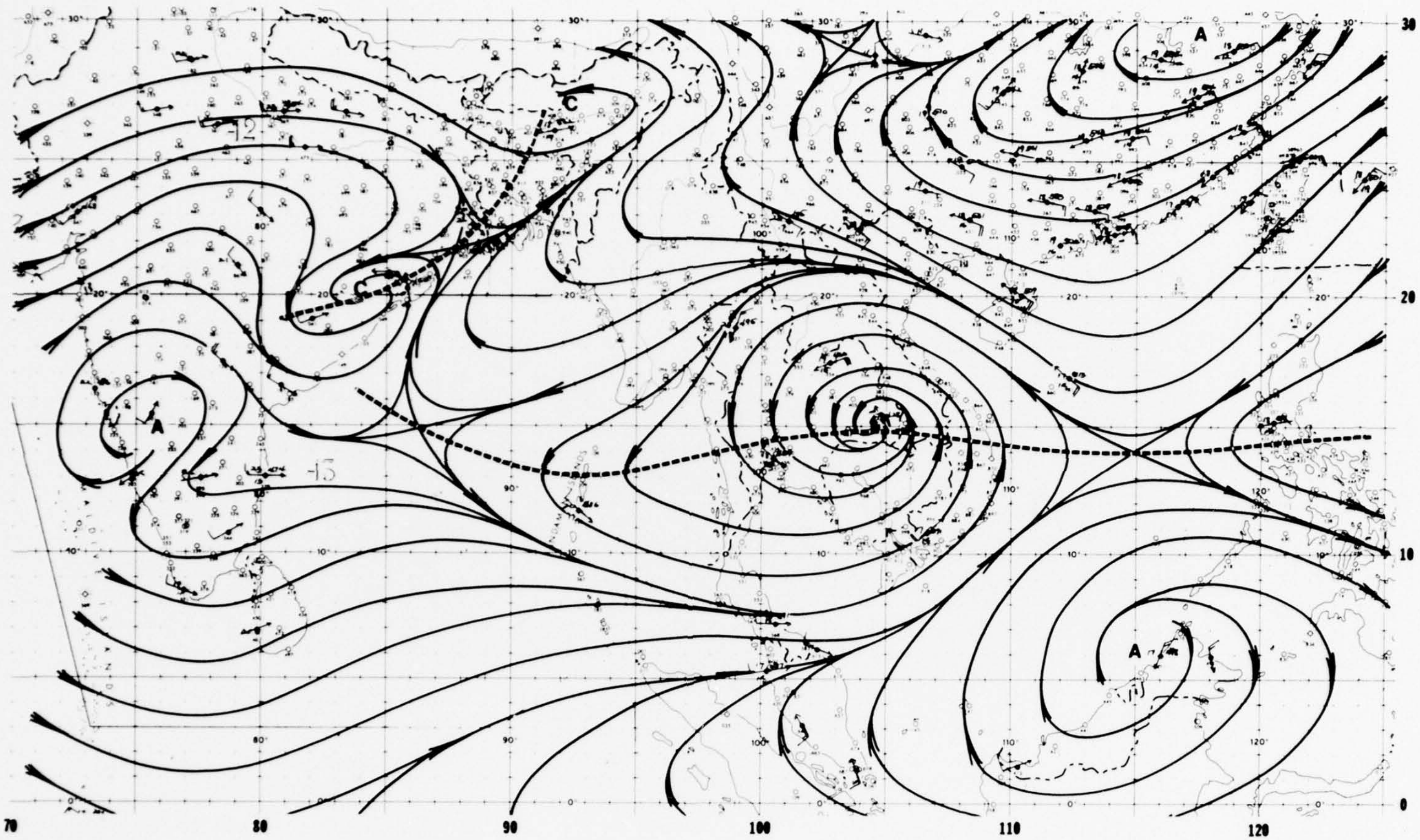

Figure 7. 850 mb wind analysis for 1200 GMT 5 September 1972.

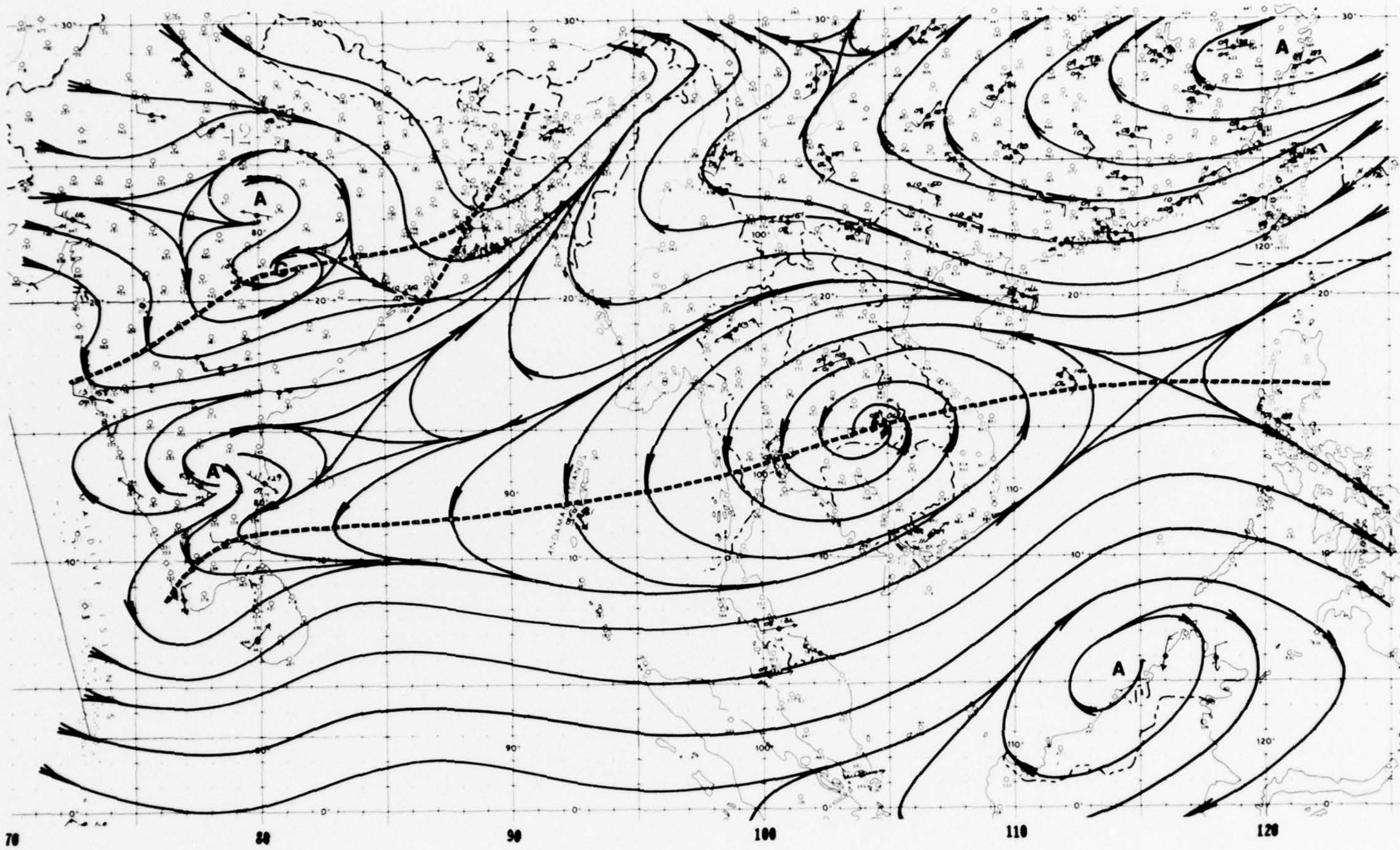

Figure 8. 700 mb wind analysis for 1200 GMT 5 September 1972.

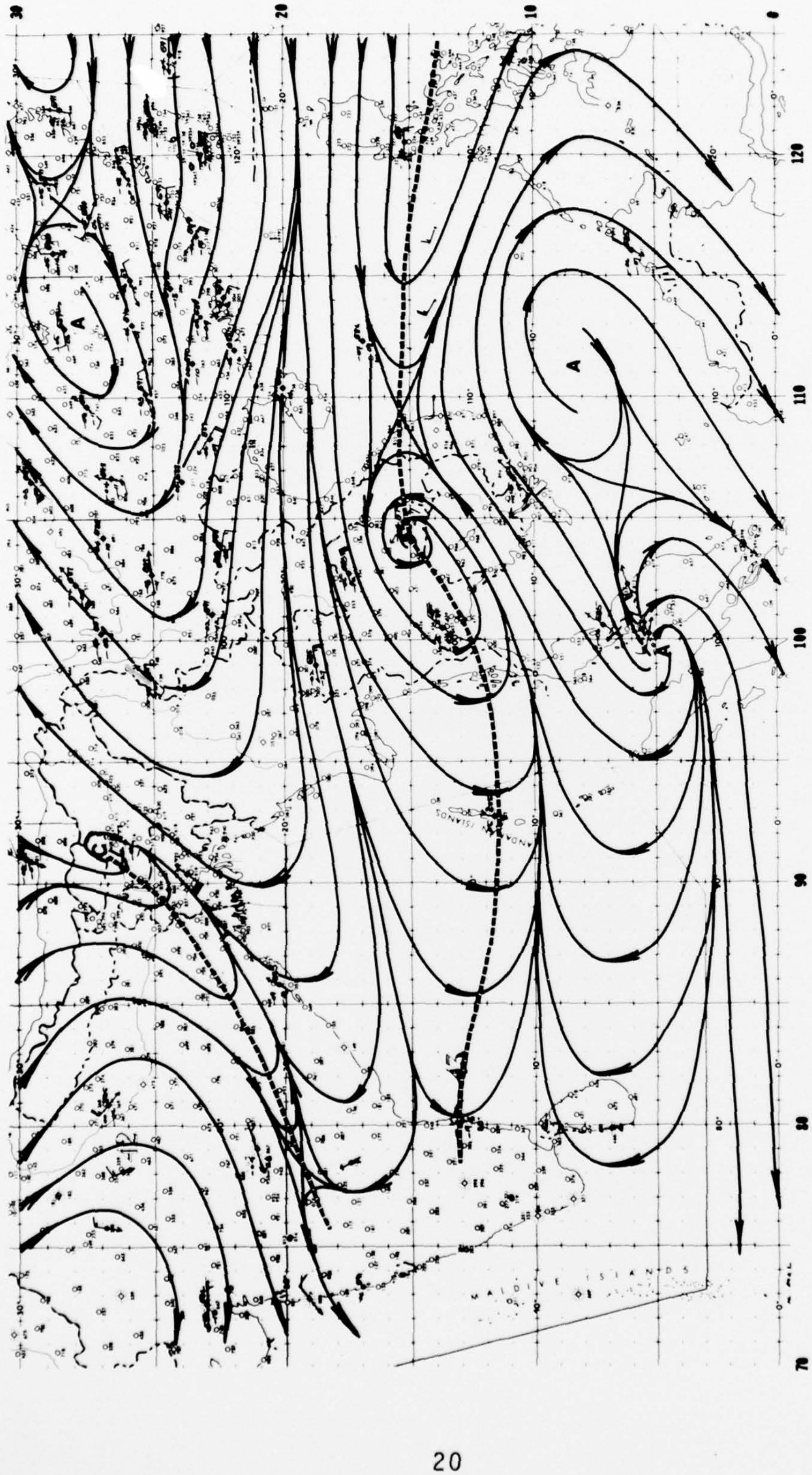

Figure 9. 500 mb wind analysis for 1200 GMT 5 September 1972.

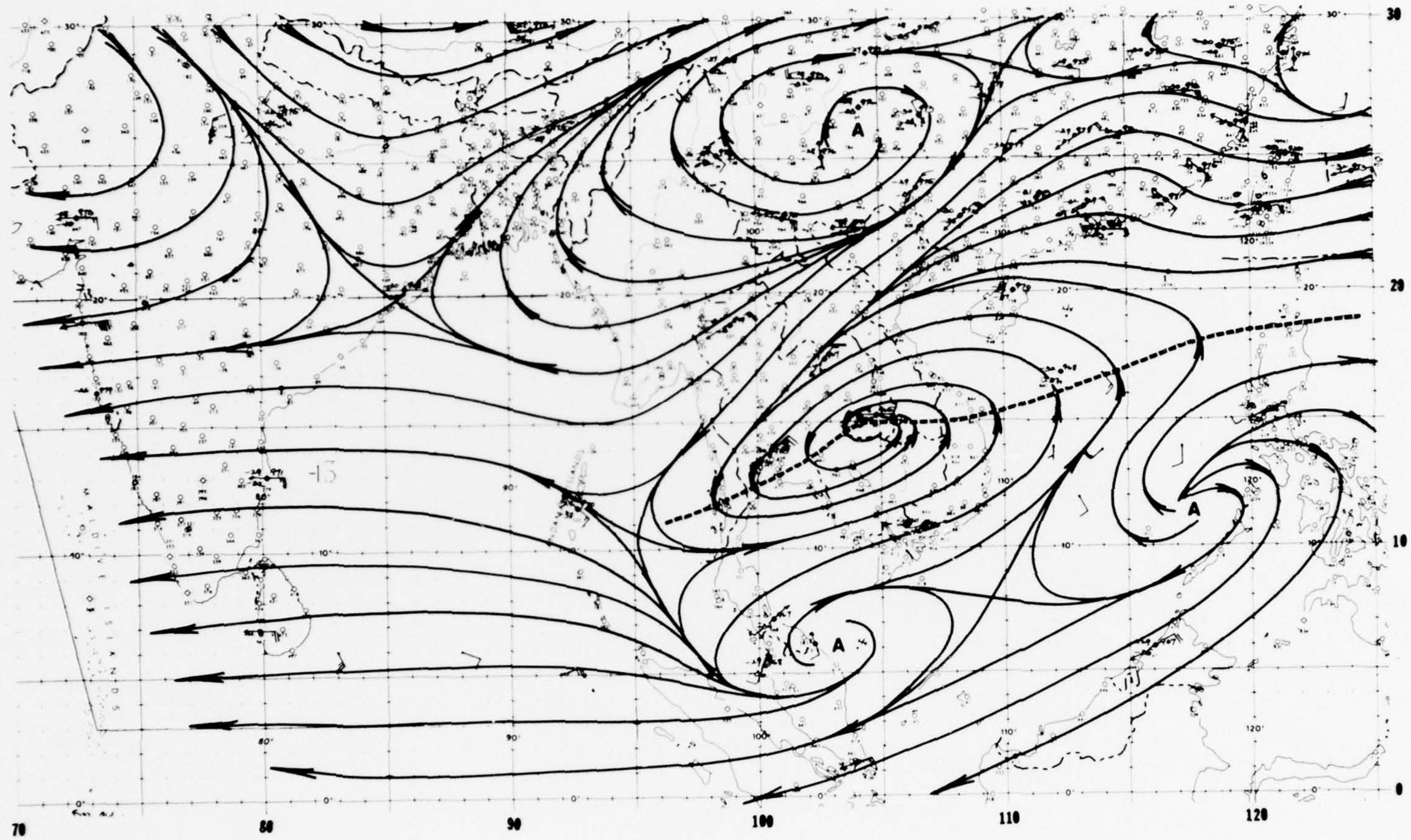

Figure 10. 300 mb wind analysis for 1200 GMT 5 September 1972.

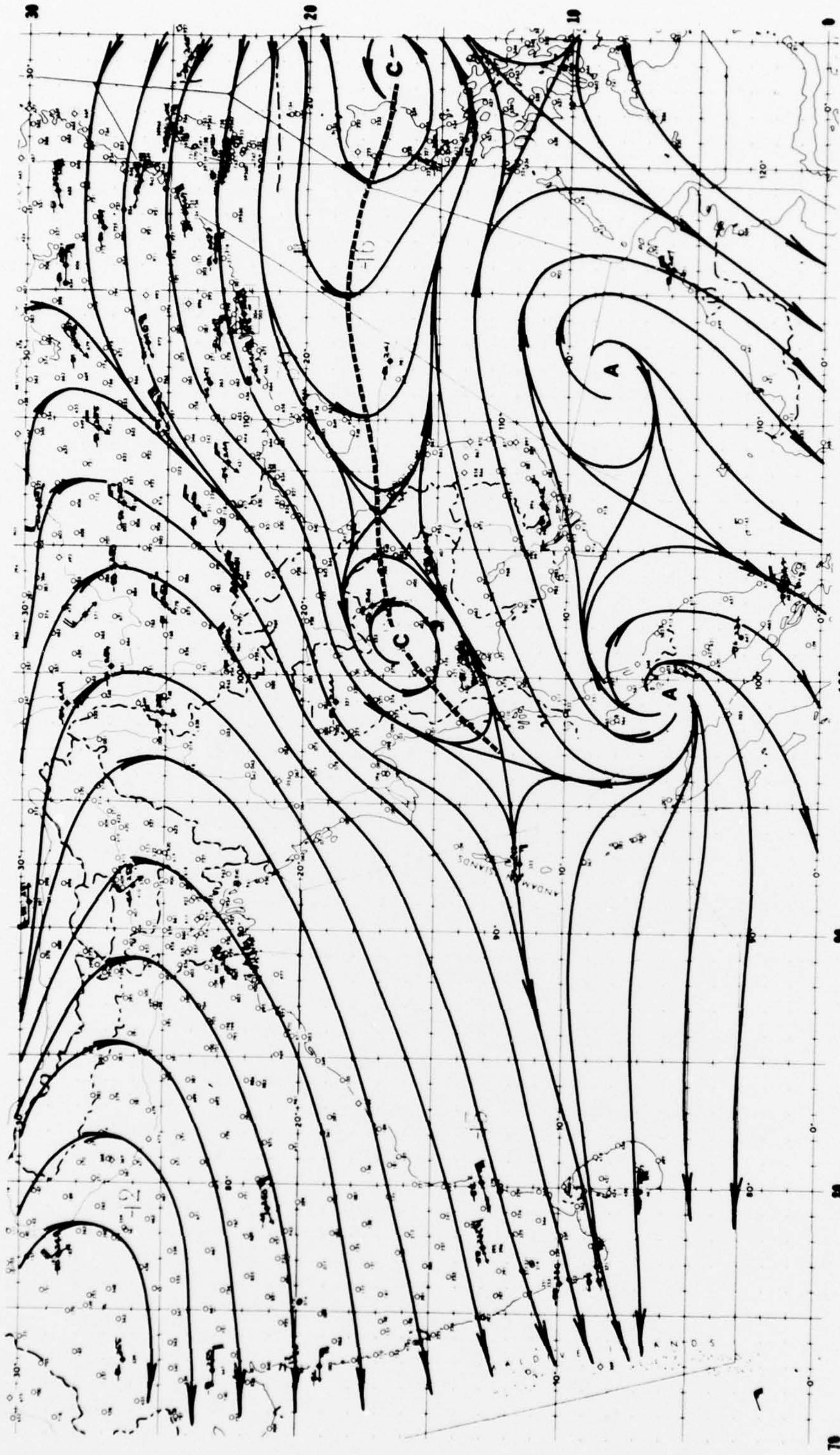

Figure 11. 200 mb wind analysis for 000 GMT 6 September 1972.

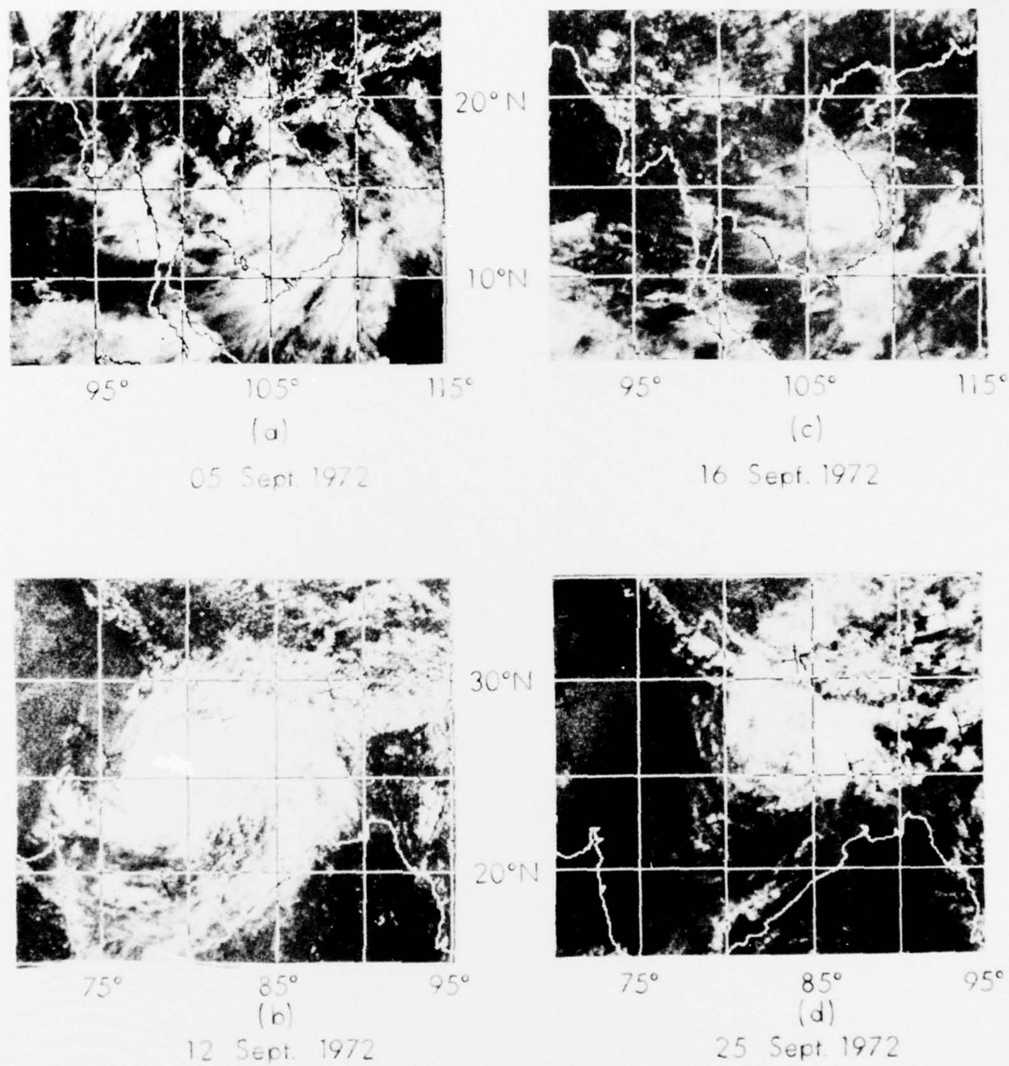

Figure 12. ESSA 9 mosaics for: (a) 0700 GMT 5 September; (b) 0845 GMT 12 September 1972; (c) 0800 GMT 16 September 1972; and (d) 0900 GMT 25 September 1972.

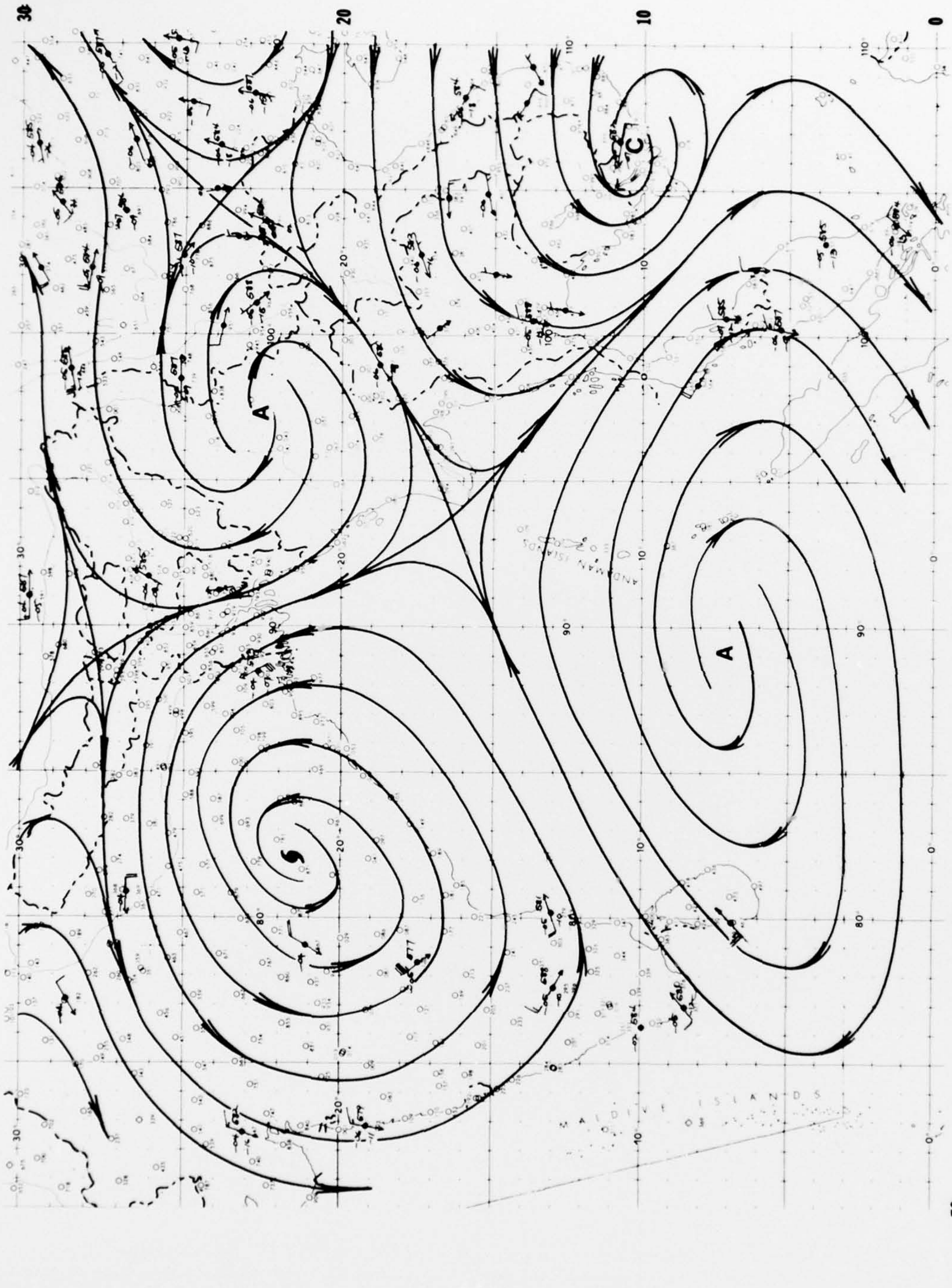

Figure 13. 500 mb wind analysis for 1200 GMT 11 September 1972.